Performance Indicators of Indoor Environmental Quality (IEQ) Assessment in Hospital Buildings: A Confirmatory Factor Analysis (CFA) Approach

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Abstract

The study identified and validated the key indicators of IEQ parameters of measurement in hospital buildings. Four-factor parameters of IEQ were assessed; such as thermal quality, acoustic quality, visual quality, and indoor air quality (IAQ). Three public hospitals in Nigeria were taken as the case study areas for the IEQ assessment. The results indicated that IEQ parameters are represented significantly by the indicator variables in the hypothesised constructs. Thermal quality has three (3) main indicator variables, while acoustic comfort has two (2). Visual quality also has two (2) main indicator variables with IAQ having only a single indicator variable. The validation of these IEQ parameter indicators can be the basis for periodic assessment of IEQ performance in hospital buildings.

Keywords: *Building performance, hospital buildings, indicators, indoor environment quality*

Introduction

There is a growing need to provide occupants of a building with an environment that is comfortable and acceptable. As such, the performance of a building indoor environmental quality (IEQ) needs to be assessed and evaluated consistently. Different building indoor environmental performance indicators and criteria have been developed and yet, most seem incomplete and not useful (Bluyssen 2010). For this reason, the level of interaction that is always seen in a given system is not taken into account in developing these indicators and criteria.

Within the building system, there is a level of interaction between the human, indoor environmental parameters, and the building which must be considered in determining a workable and useful indicator and criteria for any building performance measurement. For example, a description of an indoor environmental framework for the promotion of a healthy and comfortable environment by Bluyssen (2010) has recommended the integration of occupant comfort survey and the physical environmental elements as IEQ performance indicator. Bluyssen also stressed the necessity for a new performance indicator for building environment that promotes health and wellbeing.

Indoor environmental quality (IEQ) parameters measurement have become the main source through which building occupant comfort and wellbeing can be promoted (Guyon 2008; Hua, Oswalda & Yang, 2011). The identification and application of these parameter indicators have taken different dimensions in different studies. IEQ as defined by Healthy Heating (n.d.) consists of six metrics namely: Indoor air quality (IAQ), thermal quality, lighting quality, sound quality, indoor odour quality, and vibration quality.

However, odour and vibration are not always seen as key metrics of IEQ since they can equally be considered as variables under IAQ and acoustic quality respectively. While some IEQ studies in hospital buildings have focused on environmental variables such as temperature, relative humidity and air movement, other assessments are based on the occupants' discomfort (Khodakarami & Nasrollahi, 2012).

According to Alzoubi, Al-Rqaibat, and Bataineh (2010), IEQ in a building consists of: noise or sound, visual quality, thermal, electromagnetic waves, clean water supply, and quality of air, together with some other factors such as, environmental safety, health and building configuration. Likewise, in a study on IEQ in hospital buildings and its effect on occupant health and comfort,

Dorasol et al. (2012) categorise 15 criteria and 37 factors as indicators while Salonen et al. (2013) on their part identify 9 essential physical factors. Notwithstanding, most researches on IEQ in buildings have been based only on thermal, acoustic, visual, and indoor air quality as the main parameters in determining IEQ performance and occupants' comfort (Tarcan et al. 2004; Dascalaki et al. 2009; Croitoru et al. 2013; Mahbob et al. 2011; Sakhare & Ralegaonkar 2014).

The hospital building as a place for the sick is expected to provide a therapeutic environment for the occupants that also promote their healing processes. Therefore, having an understanding of the various indicators that influence the performance of hospital buildings' indoor environment will enhanced their performance. In Nigeria, the assessment of buildings indoor environmental quality (IEQ) has been given less attention, and those building indoor environments have negative impacts on the occupants and even the environment itself. The aim of this study was to identify and validate the IEQ parameters indicators that contribute to the performance of hospital building indoor environments. The study therefore to validated some of the indicators that have been used as determinants of IEQ based on their interrelationships, reliability and intercorrelation.

Characteristics of IEQ in Healthcare Facilities

The central theme surrounding any particular hospital is 'patient care'. Therefore, the design of a hospital should be such that the patient as the main occupant experience comfort and protection from environmental elements. The hospital is seen as a therapeutic environment for caring for the sick and other related activities such as learning and research (Ramaswamy, Al-Jahwari & Al-Rajhi, 2010). Neglecting the quality of a hospital environment will amount to issues that contradict the essence of a hospital as a healing environment. As it has been noted, there is a relationship between Sick Building Syndrome (SBS) and poor IEQ whose influence have been found to be much more on occupants in hospital buildings (Wong et al., 2009). As a result, the delicate nature of IEQ in hospital buildings as compared to other building types should be given much priority. There is now a shift from the concept of a hospital as a place for the sick to a place that support and encourage healing. The traditional hospital setting has changed tremendously with the introduction of sustainability strategies into healthcare facilities. Medical professionals are now promoting the making of hospital environment to be homely for the patient who is mostly affected by the elements of the environment (Gilmour, 2006).

The hospital which is generally seen as an environment for healing, could possibly be harmful to both people and the environment (Zimring & DuBose 2011). Besides, occupants of hospital environment could contract some healthcare acquired infections that might even result into death.

Building assessment schemes have taken

various dimensions in providing an all-inclusive evaluation at different levels of a building environment (Chiang & Lai 2002). For instance, most guidelines on IEQ assessment depends on individual parameter elements (ASHRAE 2010; ASHRAE 2004; British Standards Institution 2007; British Standards Institution 2012), which have been viewed as having a collective influence on the satisfaction level of building occupants and their task performance (Huang et al. 2012).

However, Croitoru et al. (2013) have shown in their study carried out in a hospital in Iran that, guidelines or standards are contrary to what the building occupants perceived. This study further revealed that either the hospital design was not based on standards or that standards are violating the occupant's comfort requirements. Nevertheless, the acceptability of IEQ does not depend on meeting the requirements provided for in guidelines and standards as far as occupant's perception is relevant (Bluyssen 2010). Croitoru et al. (2013) therefore, made suggestions toward developing standards that are in harmony with the requirements of building occupants in promoting their wellbeing and performance. If standards and guidelines on IEQ in buildings do not meet building occupant requirements, the need for a review is then paramount in order to harmonize between the physical environmental variables and how the occupant perceives them.

Most researches into the IEQ of hospital buildings have always considered thermal, acoustic, visual, and indoor air quality as the main parameters in determining IEQ performance and occupants' level of satisfaction (Tarcan et al. 2004; Al-Harbi 2005; Dascalaki et al. 2009; Croitoru et al. 2013). In an assessment of design indicators for better environment in hospital buildings, Zhao and Mourshed (2012), discovered that environmental design factors are more important to the occupants than architectural design features. This shows how important IEQ is to the wellbeing and comfort of occupants in hospital buildings.

Methodology

This study measured occupants' perception of IEQ performance in hospital wards of three healthcare facilities (General, Specialist, and Teaching hospitals) in Nigeria, in a bid to identify and validate performance indicators of IEQ. Confirmatory factor analysis (CFA) using Structural Equation Modelling (SEM) was employed as a quantitative technique for model validation. The three case study hospitals selected for this study were located in Jos the Plateau State capital, which is also the geographical centre of Nigeria located on latitude 9o561 N and longitude 8o531E.

The data for this study were collected based on subjective measures using structured questionnaire with an explanation to the purpose and procedure of the study. The questionnaire was developed based on the building assessment survey and evaluation (BASE) tool (US-EPA, 2003). Only the item aspect relevant to this study was extracted from the BASE questionnaire sample. This is in line with an assessment method of the physical environment developed by British Standards Institution (2012).

A total sample of 875 respondents was collected from three different hospitals in Nigeria within a period of three months consecutively. The teaching hospital represents 44.2% of the respondents, while the specialist hospital and the General hospital represent 37.4% and 18.4% of the respondents respectively. About 318 patients (36.8%) and 253 staff (28.9%) participated in the study, while the remaining 304 (34.3%) are patient relations who agreed to participate in the study as visitors. Structural equation modelling (SEM) techniques was employed in analysing the data using analysis of moment structure (AMOS) graphic software. A confirmatory factor analysis (CFA) using structural equation modelling (SEM) was used to investigate the relationships between IEQ parameters and IEQ performance.

Results

Exploratory Factor Analysis (EFA)

Exploratory factor analysis (EFA) was carried out to ascertain the level of interrelationships between the different indicator variables of a particular factor. The performance of descriptive factor analysis was based on correlation matrix using Kaiser-Meyer-Olkin (KMO) and Bartlett's Test of Sphericity. Other indices of factor analysis are the method of extraction which involved using the principal component that analysed indicators correlation matrices with Eigenvalues greater than 1 and 25 maximum iterations for convergence. The Varimax rotation method was employed with coefficient suppressed absolute value of below 0.4.

Exploratory factor analysis (EFA) of Thermal quality

Thermal quality is measured by four (4) indicator variables as shown in the results of EFA in Table1 and Table2. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy which is a determinant of the homogeneity of the Thermal quality variables was 0.815 which is greater than .6 and indicating very good internal consistency (Pallant 2007). The eigenvalues of the four indicator variables of Thermal quality was 2.803, 0.548, 0.341, and 0.308 respectively before the rotation, and accounted for the following percentage of variance, 70.069%, 13.710%, 8.518%, and 7.702% (see Table3).

After the extraction, the factor analysis extracted one (1) factor having an eigenvalue greater than 1. These indicator variables explained 70.069% of the total variance. There is therefore, an underlying relationship between Thermal quality as a factor and the four indicator variables used as its measure.

Table 1: KMO and Bartlett's Test of Thermal Quality

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.815
Bartlett's Test of Sphericity	Approx. Chi-Square	1590.322
	Df	6
	Sig.	0.000

Table 2: Communalities and Factor Matrix of Thermal Quality

	Communalities		Component Matrix[a]
Variable	Initial	Extraction	Component 1
Satisfaction with Temperature	1.000	.722	.850
Satisfaction with Air Velocity	1.000	.572	.757
Satisfaction with Relative Humidity	1.000	.734	.856
Overall satisfaction with thermal environment	1.000	.775	.880

Extraction Method: Principal Component Analysis.

Table3 :Variance Explained of Thermal Quality

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.803	70.069	70.069	2.803	70.069	70.069
2	.548	13.710	83.779			
3	.341	8.518	92.298			
4	.308	7.702	100.000			

Extraction Method: Principal Component Analysis.

Exploratory factor analysis (EFA) of Acoustic Quality

The measurement of Acoustic quality consists of three (3) indicator variables. The results of the EFA are shown in Table 4 to Table 6. The interrelationship or homogeneity of Acoustic quality indicator variables has a KMO value calculated as 0.725. The KMO value is greater than the acceptable limit of 0.60 and all the component correlation matrix values are also above 0.30. The component factor analysis extracted a single factor with an eigenvalue greater than 1, which explained 75.873% of the total variance in Acoustic quality.

Table 4: KMO and Bartlett's Test of Acoustic Quality

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.725
Bartlett's Test of Sphericity	Approx. Chi-Square	1063.189
	Df	3
	Sig.	.000

Table 5: Communalities and Factor Matrix of Acoustic Quality

	Communalities		Component Matrix[a]
Variable	Initial	Extraction	Component 1
Satisfaction with Noise Level	1.000	.741	.861
Satisfaction with Sound Privacy	1.000	.751	.867
Overall satisfaction with acoustic environment	1.000	.784	.886

Extraction Method: Principal Component Analysis.

Table 6: Variance Explained of Acoustic Quality

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.276	75.873	75.873	2.276	75.873	75.873
2	.396	13.189	89.063			
3	.328	10.937	100.000			

Extraction Method: Principal Component Analysis.

Exploratory factor analysis (EFA) of Visual quality

Visual quality is measured using four (4) indicator variables. The results of EFA shown in Table 7 to Table 9 indicate that, there is homogeneity of the four indicator variables as measures of Visual quality. The KMO value at 0.782 exceeded the 0.60 acceptance limit, also having correlation matrix of more than 0.30. The single component extracted with an eigenvalue greater than 1 explained 65.450% of the variance in Visual quality. The interrelationship that exists amongst the four indicator variables as seen in the results of the EFA is an indication of their validity as an instrument to measure Visual quality in buildings.

Table 7: KMO and Bartlett's Test of Visual Quality

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.782
Bartlett's Test of Sphericity	Approx. Chi-Square	1348.901
	Df	6
	Sig.	.000

Table8: Communalities and Factor Matrix of Visual Quality

Variable	Communalities		Component Matrix[a]
	Initial	Extraction	Component 1
Satisfaction with Daylight	1.000	.743	.862
Satisfaction with Electric Light	1.000	.674	.821
Satisfaction with Amount of Light	1.000	.439	.662
Overall satisfaction with visual environment	1.000	.762	.873

Extraction Method: Principal Component Analysis.

a. 1 components extract

Table 9: Variance Explained of Visual Quality

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.618	65.450	65.450	2.618	65.450	65.450
2	.679	16.976	82.426			
3	.413	10.330	92.756			
4	.290	7.244	100.000			

Extraction Method: Principal Component Analysis.

Exploratory factor analysis (EFA) of Indoor Air Quality (IAQ)

The instrument for measuring IAQ consists of only three (3) variables. The calculated value for the KMO is 0.548 which is less than the acceptable limit of 0.60 as suggested by Pallant (2007). However, a KMO value not less than 0.50, and having a component correlation matrix above the .30 mark is also considered as having fairly good homogeneity or internal consistency (Mooi & Sarstedt 2011). Table 10 to Table 12 show the EFA results. The factor analysis extracted a single factor with all the indicator variables explaining 62.298% of the total variance.

Table 10: KMO and Bartlett's Test of Indoor Air Quality (IAQ)

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.548
Bartlett's Test of Sphericity	Approx. Chi-Square	742.276
	Df	3
	Sig.	.000

Table 11: Communalities and Factor Matrix of Indoor Air Quality (IAQ)

Variable	Communalities		Component Matrix^a
	Initial	Extraction	Component 1
Satisfaction with Air Exchange	1.000	.249	.499
Satisfaction with Smell/Odour	1.000	.798	.893
Overall Satisfaction with IAQ	1.000	.822	.907

Extraction Method: Principal Component Analysis.

a. 1 components

Table 12: Variance Explained of Indoor Air Quality (IAQ)

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.869	62.298	62.298	1.869	62.298	62.298
2	.868	28.928	91.225			
3	.263	8.775	100.000			

Extraction Method: Principal Component Analysis.

Confirmatory factor analysis (CFA) of Thermal Quality

Thermal quality measurement in the hospital buildings consists of occupant's satisfaction with four indicator variables. From the results of EFA, these four variables interrelationship converged to an unobserved latent factor (Thermal quality). The CFA construct of Thermal quality therefore consists of four (4) variables tested using AMOS Version 22 as coded in Figure 1.

Using path analysis, the CFA measurement model showed that the goodness-of-fit values complied well with the empirical data collected for the four-indicator factor. Figure1 also shows the standardized estimates of the Thermal quality measurement model. Both estimates indicate that all the indicator variables were converged to the Thermal quality and having uncorrelated error terms in the hospital buildings.

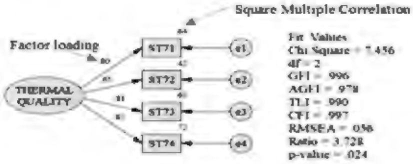

Figure1. Measurement Model of Thermal Quality (*Standardized*)

The results of maximum likelihood estimates showed that all the four indicator variables regression weights and variances had significant t-values. The most important indicator for Thermal quality is ST74 (overall satisfaction with thermal environment) having the strongest factor loading, followed by ST73 (satisfaction with relative humidity). ST72 (satisfaction with air velocity) has the least factor loading of 0.65.

Although the unidimensionality for the measurement of Thermal quality is achieved with the four indicator variables each having a factor loading which exceeded the required minimum of 0.60 (Awang, 2012), one of the indicators (ST72 – satisfaction with air velocity) has a square multiple correlation (SMC) of 0.42. The square multiple correlation of an indicator variable should not be less than 0.50 for it to be considered as a measure of a particular factor (Kline 2005). However, this measurement model was accepted and reserved for further confirmation in the second order CFA which involved other factors.

The content validity of the four indicator variables was tested using reliability test. The result of the reliability test carried out using SPSS Version 22 showed that the standard deviation of the individual variables was greater than 1.20 with a Cronbach Alpha value of 0.857. The descriptive analysis result of the Thermal quality indicator variables which was based on data collected from a total of 875 respondents is shown in Table13.

The Thermal quality measurement model as shown in Table14indicates that all absolute values of standardized residual covariances were less than 2.0. Table15shows the normality distribution of each of the variables of Thermal quality. Each of the variables has a skewness and kurtosis coefficient in absolute value of less than 1.0. The variables are therefore considered to be normal in their univariate distribution. However, multivariate normality was not achieved since the critical ratio for multivariate normality was above the acceptable limit of 5.00 (Bentler 2006). Therefore, the distribution of data based on the assessment using structural equation modelling (SEM) test showed that the properties of the variables as a measure of Thermal quality remain within acceptable value limits.

Table13: Content Validity of Measurement Model of Thermal Quality

	Variable	Mean	Std. Deviation	Cronbach's Alpha
ST71	Satisfaction with Temperature	4.27	1.423	.857
ST72	Satisfaction with Air Velocity	4.60	1.276	
ST73	Satisfaction with Relative Humidity	4.40	1.411	
ST74	Overall satisfaction with thermal environment	4.31	1.327	

Table14: Standardized Residual Covariances 5) of Thermal Quality Measurement Model

	ST74	ST73	ST72	ST71
ST74	0			
ST73	-0.189	0		
ST72	0.596	-0.242	0	
ST71	-0.087	0.387	-0.589	0

Table 15: Assessment Normality Distribution of Thermal Quality Measurement Model

Variable	Min	Max	Skew	c.r.	Kurtosis	c.r.
ST74	1	7	-0.428	-5.166	0.066	0.397
ST73	1	7	-0.407	-4.912	-0.553	-3.337
ST72	1	7	-0.621	-7.499	0.254	1.533
ST71	1	7	-0.302	-3.651	-0.5	-3.017
Multivariate					6.788	14.491

Confirmatory factor analysis (CFA) of Acoustic quality

Acoustic quality is a measure of occupant perception of background noise within the hospital ward buildings. Acoustic quality construct originally consists of three (3) indicator variables which were also accepted as relevant to the construct by the EFA carried out. The Acoustic quality measurement model when analysed using the AMOS 22 software is a just-identified model having both the chi-square value and degree of freedom (df) value equal to zero (0). This is as a result of the model having the number of distinct sample moment equalled to the number of parameters to be estimated. The Acoustic quality measurement model is accepted for further analysis and model development, as a minimum was achieved.

The structural equation model output is shown in Figure 2. The standardized estimates of the variables in the model meet the minimum requirements as all the factor loadings are greater than 0.60 and the square multiple correlation (SMC) also greater than 0.50.

Figure 2. Measurement Model of Acoustic Quality (*Standardized*)

The result of content validity of the three variables that converged as a measure of Acoustic quality is shown in Table16. The reliability of these indicator variables is very good as the Cronbach's Alpha value was 0.840 and all having a standard deviation greater than 1.2. The Cronbach's Alpha of 0.840 is an indication that the internal consistency of the indicator variables measuring Acoustic quality is acceptable (Kline 2005).

Table16: Content Validity of Acoustic Quality Measurement Model

	Variable	Mean	Std. Deviation	Cronbach's Alpha
SA81	Satisfaction with Noise Level	4.05	1.326	.840
SA82	Satisfaction with Sound Privacy	4.05	1.351	
SA83	Overall satisfaction with acoustic environment	4.20	1.270	

Table17: Assessment Normality of Acoustic Quality Measurement Model

Variable	Min	Max	Skew	c.r.	Kurtosis	c.r.
SA83	1	7	-0.204	-2.469	0.034	0.206
SA82	1	7	-0.05	-0.599	-0.407	-2.459
SA81	1	7	-0.083	-1.002	-0.525	-3.17
Multivariate					4.312	11.643

Confirmatory factor analysis (CFA) of Visual quality

Visual quality initially consists of four indicator variables which converged to one factor component as revealed by EFA. The CFA measurement model construct shown in Figure 3 indicates that, the interrelationship amongst these indicator variables complied with acceptable limits of goodness-of-fit values. The standardized and unstandardized estimates show good factor loadings on the indicators except on SV93 (satisfaction with amount of light) having a factor loading of 0.52 which is less than the acceptable limit of 0.60(Awang 2012). The indicator variable SV93 also has a square multiple correlation (SMC) value of

0.27 less than 0.50. In a CFA model, a factor is required to explain the majority of the variance of each indicator which is required to be greater than 50% (0.50) (Kline 2005). Therefore, the indicator variable SV93 is required to be deleted from the model.

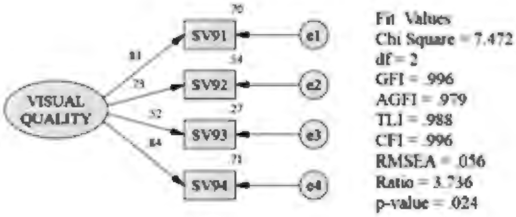

Figure 3. Measurement Model of Visual Quality (*Standardized*)

Looking at the covariances analysis in Table18 suggests that, there is a correlation between the error term e1 and e3. Deleting the indicator variable with the error term e3 might not have any effect on the model but rather, improve on the model goodness-of-fit. Table19 shows that all the standardized residual covariances analysis between a pair of variables is less than 2.0 in absolute values. The univariate skewness and kurtosis of all the observed variables were within the range -1 and +1 except SV93 whose univariate kurtosis is 1.387 (Table20). An acceptable model should have all the skewness and kurtosis to be less than 1 in absolute values in order to achieve a univariate normal distribution.

Table 18: Covariances Analysis of Visual Quality Measurement Model

	M.I.	Par Change
e1 <---> e3	5.121	-0.068

Table 19: Standardized Residual Covariances of Visual Quality Measurement Model

	SV94	SV93	SV92	SV91
SV94	.000			
SV93	.570	.000		
SV92	-.307	.324	.000	
SV91	.040	-.802	.255	.000

Table 20: Assessment Normality of Visual Quality Measurement Model

Variable	Min	Max	Skew	c.r.	Kurtosis	c.r.
SV94	1.000	7.000	-.815	-9.847	.530	3.203
SV93	1.000	7.000	-.839	-10.129	1.387	8.374
SV92	1.000	7.000	-.730	-8.817	.217	1.309
SV91	1.000	7.000	-.754	-9.100	.562	3.395
Multivariate					9.182	19.601

A new measurement model is therefore re-specified for Visual quality with SV93 deleted as illustrated in Figure 4. This model now has three (3) indicator variables having the number of distinct values in the variance-covariances sample matrix equal to the number of parameters to be estimated. As a result, none of the goodness-of-fit values were estimated having a chi-square and degree of freedom values of zero (0). This is an indication that the model is just-identified (Kline 2012). There was a convergence of the three (3) indicator variables as seen in standardized estimates shown in Figure 4.

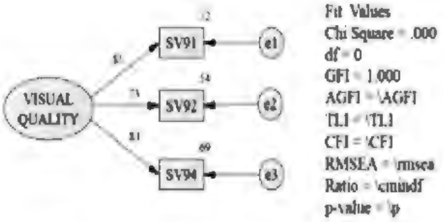

Figure 4. Modified First-Order Measurement Model of Visual Quality (*Standardized*)

The most important indicator variable as a measure of Visual quality in the hospital building is SV91 (satisfaction with daylight) having the highest factor loading of 0.85. Visual quality explains 72% (SMC = 0.72) of the total variance in SV91 (satisfaction with daylight), 54% (SMC = 0.54) of the total variance in SV92 (satisfaction with electric light) and 69% (SMC = 0.69) of the total variance in SV94 (satisfaction with overall Visual quality).

The content validity of the indicator variables as shown in Table21 indicates that they all converged to Visual quality. There was an internal consistency in the variables as the value of Cronbach's Alpha was 0.742 and having a standard deviation of greater than 1.2. Table22 shows the values of critical ratio, skewness and kurtosis of raw data. These variables which converged to Visual quality were considered to have good skewness and kurtosis for univariate normality.

Table 21: Content Validity of Modified First-Order Measurement Model of Visual Quality

	Variable	Mean	Std. Deviation	Cronbach's Alpha
SV91	Satisfaction with Daylight	5.15	1.228	.742
SV92	Satisfaction with Electric Light	4.59	1.315	
SV94	Overall satisfaction with visual environment	4.76	1.313	

Table 22: Assessment Normality of Modified First-Order Measurement Model of Visual Quality

Variable	Min	Max	Skew	c.r.	Kurtosis	c.r.
SV94	1.000	7.000	-.815	-9.847	.530	3.203
SV92	1.000	7.000	-.730	-8.817	.217	1.309
SV91	1.000	7.000	-.754	-9.100	.562	3.395
Multivariate					6.101	16.474

Confirmatory factor analysis (CFA) of Indoor air quality (IAQ)

The measurement model of IAQ consists of three (3) indicator variables that were validated when EFA was carried out. To confirm the outcome of the EFA, an initial measurement model was developed as shown in Figure 5. The model having just three (3) indicators is considered just-identified after running an analysis using AMOS 22 statistical tool. The values for the goodness-of-fit indices could not be computed since the number of distinct sample moments is the same as the number of distinct parameters to be estimated. The standardized estimates indicate that only two variables SAQ02 (satisfaction with smell/odour) and SAQ03 (Overall satisfaction with IAQ) converged as measures of IAQ in the hospital buildings. SAQ01 (satisfaction with air exchange) has a very weak factor loading of 0.28 and the IAQ only explained 8% (SMC = 0.08) of its variance

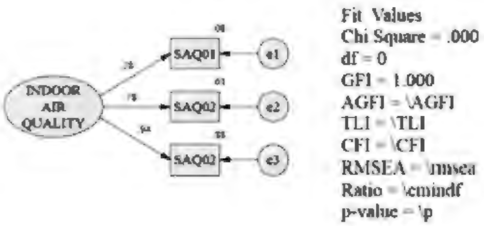

Figure 5. Measurement Model of Indoor Air Quality (*Standardized*)

Table23 and Table24 show the content validity and inter-total statistics of the measured variables. The internal consistency of the variables computed based on the Cronbach's Alpha is 0.687 which is not very good. However, the inter-total statistics shows that the Cronbach's Alpha will significantly improve from 0.687 to 0.847 if item SAQ01 is deleted. This is an indication that SAQ01 (satisfaction with air exchange) greatly affects the internal consistency of the variables as a collective measure of IAQ. The value of kurtosis for SAQ01 as provided in Table25 is greater than 1.0 which shows that this variable is not normal in its univariate distribution.

Table 23: Content Validity of IAQ Measurement Model

Variable	Mean	Std. Deviation	Cronbach's Alpha
Satisfaction with Air Exchange	4.76	1.180	.687
Satisfaction with Smell/Odour	3.55	1.471	
Overall Satisfaction with IAQ	3.58	1.419	

Table 24: Inter Total Statistics of IAQ Measurement Model

Variable	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Satisfaction with Air Exchange	7.13	7.247	.258	.070	.847
Satisfaction with Smell/Odour	8.34	4.284	.629	.541	.410
Overall Satisfaction with IAQ	8.31	4.319	.670	.552	.352

Table 25: Normality of IAQ Measurement Model

Variable	Min	Max	Skew	c.r.	kurtosis	c.r.
SAQ03	1.000	7.000	.114	1.382	-.594	-3.588
SAQ02	1.000	7.000	.213	2.569	-.599	-3.616
SAQ01	1.000	7.000	-.929	-11.218	1.240	7.487
Multivariate					2.128	5.746

A modified measurement model is therefore re-specified for IAQ having only but two indicator variables as shown in Figure 6. For a single factor CFA measurement model to be identified, it must have at least three indicator variables (Kline 2005). Since the modified IAQ measurement model has only two indicator variables, the model was reserved for further structural model testing involving more factors.

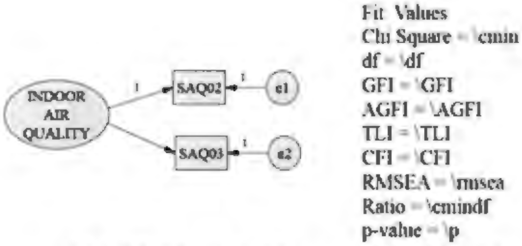

Figure 6. Modified first-order Measurement Model of Indoor Air Quality (*Unstandardized*)

The Cronbach's Alpha of the two variables is 0.847 with standard deviation greater than 1.4 as shown in Table26. The high validity and internal consistency of the two indicator variables is vital for further analysis using structural equation modelling.

Table26: Content Validity of Modified Measurement Model of IAQ

Variable	Mean	Std. Deviation	Cronbach's Alpha
Satisfaction with Smell/Odour	3.55	1.471	
Overall Satisfaction with IAQ	3.58	1.419	.847

Discriminant and convergent validity of IEQ parameters of measurement

The measurement of IEQ in buildings consists of four-factor parameters whose unidimensionality, reliability and validity have already been confirmed in the earlier subsections of this paper. For these four-factor parameters to be considered and validated as acceptable measures of IEQ performance in buildings, discriminant validity is carried out to determine if the measurement model is free from indicator variables that are redundant. The correlation between the individual exogenous factor construct must be less than 0.85 (Awang 2015) for discriminant validity to be established. The discriminant validity of IEQ measurement is a test to ascertain if the four factor parameters measure distinct construct as indirect measures of IEQ.

Figure 7 illustrate the correlation between the individual parameters of IEQ. The model is estimated both as constraint and unconstraint. Table27 shows the level of discriminant validity as a measure of the differences between the chi-square values of the constraint and unconstraint. There are differences between the chi-square values of the constraint and unconstraint model of each correlated pair of factors. For the constraint models, their chi-square values are significantly greater than the unconstraint models, as a result, discriminant validity is established (Zabkar 2000). This is an indication that each of the four factor parameters are distinct in their measurement of IEQ and were discriminant to each other.

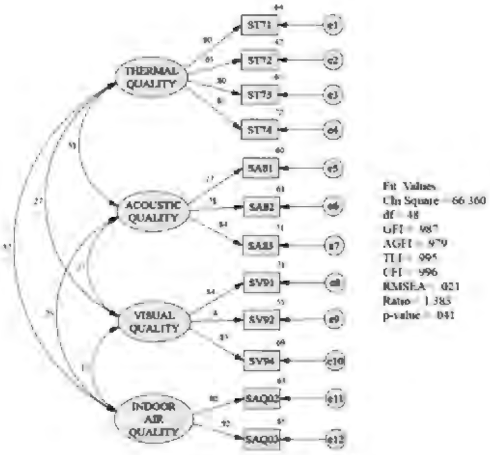

Figure 7. Discriminant Validity of IEQ Performance (*Standardized*)

Furthermore, the results of the validity test carried out using the 'Stats Tools Package'

(Gaskin 2012)as shown in Table28 is an indication that, there is no any validity concerns. All the values of the Average Variance Extracted (AVE) are greater than the Maximum Shared Variance (MSV) values. This is also an indication that discriminant validity holds for this measurement model construct. For composite reliability (CR) to be achieved, a value of CR $\geq$ 0.60 is required (Awang, 2015). The internal consistency of all the four-factor latent constructs as parameters of IEQ have composite reliability (CR), as the CR values are greater than 0.60 (Awang, 2015). Likewise, the average percentage of variation of the indicator variables of each of the parameter latent construct measured through the Average Variance Extracted (AVE) is greater than 0.50. Therefore, convergent validity can be said to be achieved for each of the paramater constructs. The indicator variables of each of the parameters are statistically significant measures in the model construct.

Table 29 shows the standardized residual covariances matrix among indicator variables of the construct factors. All the absolute values of the residual covariances were less than 2.0. A measurement model is said to be a representation of sampled data if none of the residual covariances is equal to or above 2.0 (Byrne 2010). The computed correlation matrix shown in Table30 indicated that the correlation between the exogenous factors is less than 0.850. Therefore, discriminant validity is established for Thermal quality, Acoustic quality, Visual quality, and IAQ as parameters that determine IEQ performance in buildings.

The first hypothesised measurement model examined the interrelationships that exist among Thermal quality, Acoustic quality, Visual quality, and IAQ as parameters of IEQ. The analysis of results based on the level of internal consistency, inter-correlation and convergent validity have shown that all the four factor parameters measurement construct have reliability coefficient above 0.70. The measured variables have their factor loadings above 0.60 and square multiple correlation greater than 0.40.

Table 27: Discriminant Validity of IEQ Performance

Pairwises	Constraint		Unconstraint		Diferrence	
	χ^2	Df	χ^2	Df	χ^2	Df
Thermal Quality » Acoustic Quality	107.08	14 (p=.000)	17.724	13 (p=.168)	89.351	1 (p=.168)
Thermal Quality » Visual Quality	132.51	14 (p=.000)	30.643	13 (p=.004)	101.867	1 (p=.004)
Thermal Quality » IAQ	65.638	9 (p=.000)	12.542	8 (p=.129)	53.096	1 (p=.129)
Acoustic Quality » Visual Quality	13.171	9 (p=.155)	12.87	8 (p=.116)	0.301	1 (p=.039)
Acoustic Quality » IAQ	6.554	5 (p=.256)	6.254	4 (p=.181)	0.3	1 (p=.075)
Visual Quality » IAQ	8.499	5 (p=.131)	5.098	4 (p=.277)	3.401	1 (p=.146)

Table 28: Validity Test of IEQ Performance from Stats Tools Package

Variable	CR	AVE	MSV	ASV	IAQ	Thermal_Quality	Acoustic_Quality	Visual_Quality
IAQ	0.852	0.743	0.100	0.064	0.862			
Thermal_Quality	0.860	0.608	0.100	0.091	0.317	0.780		
Acoustic_Quality	0.842	0.639	0.097	0.077	0.248	0.312	0.800	
Visual_Quality	0.848	0.650	0.074	0.059	0.171	0.272	0.269	0.806

No Validity Concerns -

Table 29: Standardized Residual Covariancessof IEQ Performance

	SAQ03	SAQ02	SV94	SV92	SV91	SA83	SA82	SA81	ST74	ST73	ST72	ST71
SAQ03	.000											
SAQ02	.000	.000										
SV94	-.023	-.642	.000									
SV92	1.173	.949	-.166	.000								
SV91	-.383	-.667	.104	-.026	.000							
SA83	.354	.076	-.059	.125	-.389	.000						
SA82	-.656	-.508	-.281	1.248	-.250	.037	.000					
SA81	.533	-.688	-.332	1.713	-.274	-.050	.016	.000				
ST74	-.750	-.281	.635	1.300	-.535	.068	-.656	-.050	.000			
ST73	.082	.591	-.933	1.061	-.978	-.806	-.550	-.148	-.119	.000		
ST72	.793	.390	1.613	2.779	.768	.471	-.315	1.017	.534	-.304	.000	
ST71	.192	.610	-.597	.670	-1.531	.610	.739	.476	-.074	.394	-.697	.000

Table 30: Correlation Matrix of Exogenous factors of IEQ Performance

Variable	Indoor Air Quality	Visual Quality	Acoustic Quality	ThermalQuality
Indoor Air Quality	1.000			
Visual Quality	.171	1.000		
Acoustic Quality	.248	.269	1.000	
Thermal Quality	.317	.272	.312	1.000

Discussion

The analysis of CFA measurement models show that the four-factor parameters of IEQ as latent variables were measured indirectly by different observable indicator variables. The validity of these indicator variables was based on content reliability, construct validity and convergent validity. The analysis of content validity indicated that there is internal consistency between the indicator variables as measures of IEQ parameters.

Thermal quality has four (4) indicator variables (ST71 – satisfaction with temperature, ST72 – satisfaction with air velocity, ST73 – satisfaction with relative humidity, and ST74 – overall satisfaction with thermal environment) which are all reliable indicators having a Cronbach's Alpha coefficient of 0.857. The correlation among the three indicator variables of acoustic quality (SA81 – satisfaction with noise level, SA82 – satisfaction with sound privacy, and SA83 – overall satisfaction with acoustic environment) has an internal consistency with a Cronbach's Alpha coefficient of 0.840. Visual quality on the other hand initially had four (4) indicator variables (SV91 – satisfaction with day light, SV92 –

satisfaction with electric light, SV93 – satisfaction with amount of light, and SV94 – overall satisfaction with visual environment).

After conducting CFA, the indicator variable SV93 was deleted from the construct as a result of having a low factor loading below 0.60 and low square multiple correlation less than 0.50. The variation in visual quality as a latent factor is only accounted for by 27% of SV93, it was therefore deleted from the model construct. The remaining three indicator variables of visual quality have a Cronbach's Alpha coefficient of 0.742 which is an indication of good reliability. For IAQ, one of the three (3) indicator variables (SAQ01 – satisfaction with air exchange) could not load very well on the IAQ latent factor resulting into having a very low square multiple correlations (0.08). This indicator SAQ01 was deleted from the IAQ construct leaving only two indicator variables (SAQ02 – satisfaction with smell/odour, SAQ03 – overall satisfaction with IAQ), since it could not account for up to 10% of the variance in IAQ. The value of Cronbach's Alpha for the remaining two indicators was quite high (0.847) giving a high internal consistency and reliability.

The construct validity based on the hypothesised CFA models of thermal quality (four indicators), acoustic quality (three indicators), visual quality (three indicators), and IAQ (two indicators) have acceptable goodness-of-fit values to the sampled data. All the indicator variables of the four-factor parameters have their factor loading greater than 0.60 and square multiple correlation of not less than 0.4, therefore, convergent validity is established.

The results from this study have shown that the IEQ parameters were represented significantly by the accepted indicator variables. In particular, thermal quality is represented by temperature, air velocity and relative humidity which is consistent with what other researchers have considered in their measurement of thermal quality (Dascalaki et al. 2008; Mahbob et al. 2011; De Giuli et al. 2013). However, there are other studies that only considered two variables (temperature and relative humidity) as indicators of thermal quality in buildings (Fransson et al. 2007; Yoon 2008; Ng 2011; Azizpour et al. 2012; Huang et al. 2013). Notwithstanding, the goodness-of-fit values and the various estimates of the thermal quality construct model is an indication that temperature, relative humidity and air velocity are valid indicators.

Acoustic quality on the other is represented by noise level and sound privacy as the main indicator variables. Although, this result differs from some other studies on acoustic quality that only considered noise levels (Brown & Cole 2009; Cao et al. 2012; Croitoru et al. 2013; Dascalaki et al. 2009; Fransson et al. 2007) as the indicator, it is consistent with studies which adopted the centre for built environment (CBE) web-based occupant IEQ survey (Jensen & Arens 2005; Zagreus et al. 2004; Frontczak & Wargocki 2011). Out of the four indicators of visual quality, only three (3) were validated. Visual quality depends on the amount of light in an indoor space of which daylight and electric light are the main contributors. For IAQ, the main and only perceived determinant is either smell or odour as shown in the measurement model.

Conclusion

From the measurement models developed using Structural Equation Modelling (SEM), this study has shown that Thermal quality, Acoustic quality, Visual quality, and IAQ are valid parameters that determine IEQ performance in hospital wards. These parameters are indirectly measured through the interrelationships among three (3) indicator variables of thermal quality, two (2) indicator variables of acoustic quality, two (2) indicator variables of visual quality, and one (1) indicator variable of IAQ. The level of inter-correlation and covariation amongst these indicator variables have shown that composite reliability, convergent validity and discriminant validity have been achieved for the four-factor parameters.

The specified model which tested discriminant and convergent validity is an indication of the interrelationship among the four-factor parameters as determinants of IEQ in buildings. This model therefore ascertains the validity of IEQ parameters as factors that contribute to the performance of a hospital building environment.

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